The LHCb anomalies in the composite Higgs scenario

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based on E. Megías, GP, O. Pujolàs and M. Quirós arXiv:1608.02362
(see also arXiv:1705.04822)
Hints of new physics in B decays

A coherent pattern of deviations in B-meson physics seems to emerge from the flavour measurements

✦ hints of **lepton universality violation** in clean observables $R_K$ and $R_{K^*}$

$$R_K = \frac{\text{BR}(B^+ \rightarrow K^+\mu^+\mu^-)}{\text{BR}(B^+ \rightarrow K^+e^+e^-)} = 0.745^{+0.090}_{-0.074} \pm 0.036$$

$$R_{K^*} = \frac{\text{BR}(B^+ \rightarrow K^{*+}\mu^+\mu^-)}{\text{BR}(B^+ \rightarrow K^{*0}e^+e^-)} = \begin{cases} 0.660^{+0.110}_{-0.070} \pm 0.024 \\ 0.685^{+0.113}_{-0.069} \pm 0.047 \end{cases}$$

✦ additional deviations in other process related to the $b \rightarrow s \mu\mu$ transition
A simple pattern?

Compatibility with the data can be significantly improved if sizeable contributions to $O_9$ (possibly correlated to $O_{10}$) are present

$$\Delta C_9^\mu \in [-1.43, -0.74]$$

$$\Delta C_9^\mu = -\Delta C_{10}^\mu \in [-0.87, -0.36]$$

Many BSM models have been proposed to explain the anomalies

- leptoquarks

  [Kosnik '12, Hiller, Schmaltz '14; Sahoo, Mohanta '15; Becirevic, Fajfer, Kosnik '15; ...]

- heavy Z' vectors

  [Altmannshofer et al. '13; Gauld, Goertz, Haisch '13; Altmannshofer et al. '14; Crivellin et al. '15; Sierra, Straub, Vicente '15; Celis, Fuentes-Martin, Jung, Serodio '15; Falkowski, Nardecchia, Ziegler '15; Descotes-Genon, Hofer, Matias, Virto '15; ...]
Looking for a bigger picture

Sizeable contributions are needed to reproduce the anomalies

⇒

generic feature of new physics: new states with a mass \( \sim \text{TeV} \)

Could it be first hint of a bigger picture?

✦ intriguing possibility:

relate the anomalies to the **Naturalness Problem**

‣ in this talk: explore this possibility in the context of scenarios with a **composite Higgs** and new strongly-coupled dynamics
Model-independent overview
Composite Higgs: General features

New strongly-coupled dynamics at a scale \( \Lambda \sim \text{TeV} \)

- **composite** Higgs boson \( H \)
  - EW scale naturally of order \( \Lambda \) \( \rightarrow \) solution of the Naturalness Problem

- **new massive resonances** \( m \sim \text{TeV} \)
  - heavy vectors \( \rho \) (same quantum numbers as SM gauge fields)
  - fermionic partners \( \psi \) (mixed with SM fermions: partial compositeness)
The $b \rightarrow sll$ transition

Vector resonances generate contributions to the $O_9$ and $O_{10}$ operators

$$\Delta C^\mu_9 \sim \Delta C^\mu_{10} \sim -\frac{\sqrt{2}\pi}{G_F\alpha_{em}} s_b^2 s_\mu^2 \left( \frac{g_\rho}{m_\rho} \right)^2$$

$$\simeq -0.4 \left( \frac{1 \text{ TeV}}{m_\rho/g_\rho} \right)^2 \left( \frac{s_b}{0.3} \right)^2 \left( \frac{s_\mu}{0.3} \right)^2$$

- the B anomalies can be easily reproduced if the $b$ and the $\mu$ have some amount of compositeness

$$s_b \sim s_\mu \sim 0.3 \quad (m_\rho \sim \text{few TeV}, \ g_\rho \sim \text{few})$$

- electron almost elementary: violation of lepton universality

- preferred pattern: left-handed compositeness

$$s_{bL} \sim s_{\mu L} \sim 0.3 \quad s_{bR} \sim s_{\mu R} \ll 0.1 \quad \Delta C^\mu_9 \simeq -\Delta C^\mu_{10}$$

see also [Niehoff, Strangl, Straub '15]
The $b \rightarrow s l l$ transition

Additional effects from Z exchange

$$\Delta C^e_{10} = \Delta C^\mu_{10} \sim \frac{\sqrt{2} \pi}{G_F \alpha_{em}} s_{bL}^2 \frac{g^2_\rho}{m^2_\rho}$$

- Induced after EWSB by mixing:
  - Z boson with vector states
  - elem. fermions with partners

- Coupling to leptons mediated by Z current:
  - lepton flavor universal: do not modify $R_K$ and $R_{K^*}$
Implications for flavour and EW physics

The vector resonances give rise to other unavoidable effects

distortion of the $Z$ and $W$ couplings

$\Delta F = 2$ transitions
The distortion of the Z couplings can lead to strong constraints

\[
\frac{\delta g_{Z f_L f_L}}{g_{Z f_L f_L}^{SM}} \sim s_{f_L}^2 \frac{g_\rho^2}{m_\rho^2} \frac{v^2}{2} \sim 2 \times 10^{-3} \left( \frac{s_{f_L}}{0.3} \right)^2 \left( \frac{1 \text{ TeV}}{m_\rho / g_\rho} \right)^2
\]

from the current constraints one finds an upper bound on the amount of $b$ and $\mu$ compositeness

\[
\frac{\delta g_{Z f_L f_L}}{g_{Z f_L f_L}^{SM}} \lesssim \text{few} \times 10^{-3} \quad \Rightarrow \quad s_{b_L}, s_{\mu_L} \lesssim 0.3
\]

\[\Rightarrow\] constraints close to values needed to explain B anomalies

\[
\Delta C_{9,10}^\mu \sim -0.4 \left( \frac{m_\rho / g_\rho}{1 \text{ TeV}} \right)^2 \left( \frac{\delta g_{Z b_L b_L}}{g_{Z b_L b_L}^{SM}} / 10^{-3} \right) \left( \frac{\delta g_{Z \mu_L \mu_L}}{g_{Z \mu_L \mu_L}^{SM}} / 5 \times 10^{-3} \right)
\]
More on the Z and W couplings

Deviations in the Z couplings to $\mu$ and $b$ can be avoided in models with custodial symmetry by imposing a $P_L P_R$ invariance

... but the couplings involving $\nu_\mu$ can not be protected!

$$\frac{\delta g_{W\mu\nu_\mu}}{g_{W\mu\nu_\mu}^{SM}} \sim \frac{\delta g_{Z\nu_\mu\nu_\mu}}{g_{Z\nu_\mu\nu_\mu}^{SM}} \sim 2 \times 10^{-3} \left( \frac{s_{\mu L}}{0.3} \right)^2 \left( \frac{1 \text{ TeV}}{m_\rho/g_\rho} \right)^2$$

- Tested with very good accuracy ($few \times 10^{-3}$)
  - muon decay (extraction of Fermi constant)
  - Z boson width

⇒ deviations close to the experimental bounds if we want to explain B anomalies
**$\Delta F = 2$ transitions**

Vector resonances also mediate $\Delta F = 2$ effective interactions

\[ O_{\Delta F=2}^{LL} \sim s_{b_L}^4 \left( \frac{g_\rho}{m_\rho} \right)^2 (V_{3i}^* V_{3j})^2 (\overline{d}_i L \gamma^\mu d_j L)^2 \]

\[ \approx \frac{1}{(10 \text{ TeV})^2} \left( \frac{s_{b_L}}{0.3} \right)^4 \left( \frac{1 \text{ TeV}}{m_\rho/g_\rho} \right)^2 (V_{3i}^* V_{3j})^2 (\overline{d}_i L \gamma^\mu d_j L)^2 \]

- current flavor bounds imply the constraint

\[ s_{b_L}^4 \left( \frac{g_\rho}{m_\rho} \right)^2 \lesssim \frac{1}{(5 \text{ TeV})^2} \quad \rightarrow \quad s_{b_L} \lesssim 0.4 \]

- constraints close to values needed to explain B anomalies
An explicit model

B-anomalies from RS
A modified RS scenario

An explicit realization can be obtained in an extra-dimensional scenario a la Randall-Sundrum

\[ ds^2 = e^{-2A(y)} \eta_{\mu\nu} dx^\mu dx^\nu + dy^2 \]

- **Higgs** is a composite state  
  localized towards the IR brane

- **fermion compositeness** controlled by the bulk mass \( c_f \)
  - almost elementary \( c_f > 0.5 \)  
    (UV localized)  
  - sizeable compositeness \( c_f \lesssim 0.5 \)  
    (IR localized)
EW bounds

EW correction to oblique $S, T$ parameters under control by small deformation of the metric close to IR

typical mass of the **lightest gauge KK’s**

$$m^{(1)}_\rho \sim 2 - 3 \text{ TeV}$$

a **light dilaton** could also be present

$$m_{dil} \sim 0.1 - 3 \text{ TeV}$$

- still allowed due to reduced couplings to SM
Reproducing the B anomalies

- the B anomalies can be easily reproduced

- compelling scenario with $b$ and $\mu$ localization fixed
  - correlated effects in $\Delta F = 2$ transitions, $Z$ and $W$ couplings close to experimental bounds
Heavy gluon KK modes: expected to have a mass comparable with the EW gauge resonances
- copiously produced at LHC: current bounds $m_{KK} \gtrsim 2$ TeV
- natural region of parameter space testable soon

EW gauge KK modes: enhanced couplings to muons
- harder to produce, possibly visible if light quarks are not too elementary

Fermionic KK modes
- typical mass in the few TeV region
- quark KK partners testable in future LHC runs
Conclusions

Anomalies in B physics seem to follow a coherent pattern, possibly pointing to violation of lepton universality.

Models with a **composite Higgs** and new strong dynamics can explain the anomalies and link them to the **Naturalness Problem**

- **generic features:**
  - sizeable **muon** and **bottom compositeness**
  - related **deviations** in $Z$ and $W$ couplings and $\Delta F = 2$ transitions
  - **heavy resonances at the TeV scale** testable at the LHC
    - (heavy gluons, heavy vectors, fermionic partners)

- **flavor symmetries needed in lepton sector**...

- **predictive explicit implementations in extra-dimensions**
Backup
Breaking lepton universality

**SM gauge fields** (KK zero modes) have flat profiles

\[ \downarrow \]

flavor-universal couplings
(up to small corrections after EWSB)

**Massive KK modes** have a non-trivial profile: IR localized

\[ \downarrow \]

stronger couplings with composite fields:
universality violation